Status of Pelagic Prey Fishes in Lake Michigan, 2011[1]

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ABSTRACT

Acoustic surveys were conducted in late summer/early fall during the years 1992-1996 and 2001-2011 to estimate pelagic prey fish biomass in Lake Michigan. Midwater trawling during the surveys as well as target strength provided a measure of species and size composition of the fish community for use in scaling acoustic data and providing species-specific abundance estimates. The 2011 survey provided data from 24 acoustic transects (442 km) and 26 midwater tows. Mean total prey fish biomass was 4.8 kg/ha (relative standard error, RSE = 23%) or ≈25.6 kilotonnes (kt = 1,000 metric tons), which was only 24% of the estimate for 2010 and 16% of the long-term mean. The decrease from 2010 was the largest single-year decrease in the time series and resulted from decreased biomass of age-1 and older alewife as well as a weak 2011 year class. The weak 2011 year class was the result of very low spawner densities rather than early mortality. The 2011 alewife year-class contributed <1% of total alewife biomass (3.5 kg/ha, RSE = 25.0%), while the 2010 alewife year-class contributed ≈68%. In 2011, alewife comprised 72% of total prey fish biomass, while rainbow smelt and bloater were 16 and 12% of total biomass, respectively. Rainbow smelt biomass in 2011 (0.75 kg/ha, RSE = 38%) was similar to biomass in 2010 (0.6 kg/ha). Bloater biomass was much lower (0.6 kg/ha, RSE = 31%) than in the 1990s, and mean density of small bloater in 2011 (4 fish/ha, RSE = 23%) was the lowest observed in any acoustic survey on record. Previous high densities of small bloater (2007-2009) appear to have resulted in minimal recruitment to larger sizes. In 2011, pelagic prey fish biomass in Lake Michigan was much lower than in Lake Huron for the first time in the eight years in which acoustic surveys were done in both lakes. Prey fish biomass remained well below the Fish Community Objectives target of 500-800 kt, and key native species remain absent or rare.

INTRODUCTION

In light of changes in the Lake Michigan food web during the last 40 years (Madenjian et al. 2002) and the continuing anthropomorphic influences through introduction of exotic species, pollution, fishing, and fish stocking, regular evaluation of long-term data on prey fish dynamics is critical. The traditional Great Lakes Science Center (GLSC) prey fish monitoring method (bottom trawl) is inadequate for fish located off bottom (Fabrizio et al. 1997). In particular, bottom trawls provide particularly biased estimates for age-0 alewives (*Alosa pseudoharengus*), rainbow smelt (*Osmerus mordax*), or bloater (*Coregonus hoyi*), although the bottom trawl estimate for age-0 bloater has been documented to predict recruitment to age-3 (or year-class strength; Bunnell et al. 2010). Alewives are the primary prey of introduced salmonines in the Great Lakes (Stewart and Ibarra 1991; Elliott 1993; Rybicki and Clapp 1996; Warner et al. 2008), and, as such, constitute an important food web component. Alewife dynamics typically reflect occurrences of strong year-classes and total alewife density is highly correlated with the density of alewife ≤ age-2 (Warner et al. 2008). Much of the alewife biomass will not be recruited to bottom trawls until age-3 (Madenjian et al. 2005), but significant predation by salmonines may occur on alewives ≤ age-2 (Warner et al. 2008). Because of the ability of acoustic equipment to count organisms far above bottom, this type of sampling is ideal for highly pelagic fish like age-0 alewives, rainbow smelt, and bloater and is a valuable complement to bottom trawl sampling.

METHODS

Sampling Design

The initial Lake Michigan survey adopted by the Lake Michigan Committee (Fleischer et al. 2001) was a stratified quasi-random design with three strata (north, south-central, and west) and unequal effort allocated among strata. The location of strata and number of transects within each stratum was determined from a study of geographic distribution of species and the variability of fish abundance within strata (Argyle et al. 1998). A modified design (Figure 1) was developed in 2004 (Warner et al. 2005), which included two additional strata (north and south offshore). The initial three strata were retained, but their size was modified based on data collected in 2003 as well as NOAA CoastWatch Great Lakes node maps of sea surface temperature from 2001-2003. In 2007-2011, the number of transects in each stratum was optimized based on stratum area and standard deviation of total biomass using methods in Adams et al. (2006).
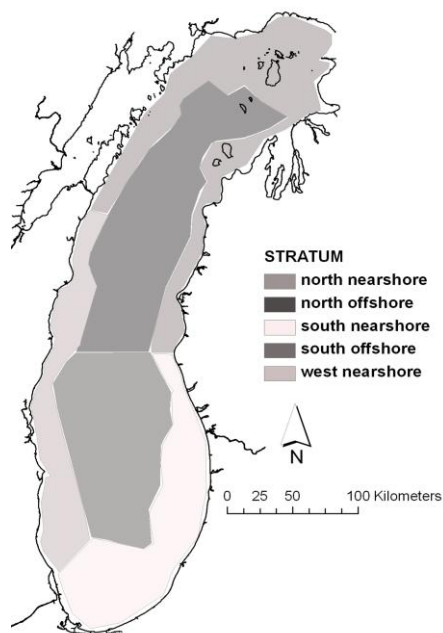

Figure 1. Map of Lake Michigan showing strata used in design and analysis of the lakewide acoustic survey conducted in 2009.

Fish Data Collection and Processing

The lakewide acoustic survey has been conducted as a cooperative effort in most years. In 2011, three agencies (United States Geological Survey, U.S.G.S., Michigan Department of Natural Resources, M.D.N.R., and United States Fish and Wildlife Service U.S.F.W.S.) contributed to the completion of the survey. Sampling has been conducted between August and November, with acoustic data collection initiated ≈ 1 hour after sunset and ending ≈1 hour before sunrise. Several different vessels have been used ranging in length from 10-32 m with sampling speeds ranging from 5-11 km/hour. Different echosounders have been used through the years (Biosonics 102 dual beam, DE5000 dual beam, DT split beam, DT-X split beam and Simrad EK60 split beam). However, acoustic data have always been

collected using echosounders with a nominal frequency of 120 kilohertz. With the exception of one unit used in 2001, echosounders have been calibrated during the survey using methods described in Foote et al. (1987) and MacLennan and Simmonds (1992). Transducer deployment techniques have included a towfish, sea chests (Fleischer et al. 2002), hull mounting, and sonar tubes. Different deployment methods cause variation in the depth of the transducer, and sea chest, hull mount, and sonar tube methods result in a larger portion of the upper water column remaining unsampled because the transducer is deeper. However, fish density estimates in the area sampled with all deployment techniques are comparable.

Midwater trawls were employed to identify species in fish aggregations observed with echosounders and to provide size composition data. Tows targeted aggregations of fish observed in echograms while sampling, and typically trawling locations were chosen when there was uncertainty about the composition of fish aggregations observed acoustically. A trawl with a 5-m headrope and 6.35-mm bar mesh cod end was fished from the S/V Steelhead in 1992-2009. In 2010 and 2011, a larger trawl (12 m headrope) with the same codend mesh size was used on the S/V Steelhead. On the U.S.G.S. vessel R/V Grayling, a variety of trawls were used (Argyle et al. 1998). On the U.S.G.S. vessels R/V Siscowet, R/V Kiyi and R/V Sturgeon (2001 to present), a trawl with ≈15 m headrope and 6.35-mm bar mesh cod end was used. On the U.S.F.W.S. vessel, a 21-m trawl with 6.35-mm bar mesh cod end was used. In the 1990s, trawl depth was monitored using net sensors. Similar sensors were used in 2001-2005 (except 2002 on U.S.G.S. vessel, 2001-2004 on M.D.N.R. vessel). In cases without trawl sensors, warp length and angle were used to estimate fishing depth. From 2005 onward, trawl sensors have been used on all trawls. Given the size of fish present, we expect little influence of trawl size on species and size composition data.

Fish were measured as total length (TL, mm) either in the field or frozen in water and measured upon return to the laboratory. Lengths of fish in large catches of a given species (> 100 fish) were taken from a random subsample. Fish were weighed in groups (total catch weight per species, nearest 2 g) in the field or individually in the laboratory (nearest 0.1 g). Total catch weight was recorded as the sum of weights of individual species. Rainbow smelt were assigned to two size categories (< 90 mm, ≥ 90 mm), while the size cutoff for bloater was < or ≥ 120 mm. The small size category for these two species is predominantly age-0, while the large size category consists of fish that are predominantly age-1 and older. Alewives were assigned to age classes using an age-length key based on sagittal otolith age estimates. Age-length keys were available for each year except 1992. The key for 1992 was constructed by averaging the 1991 and 1993 keys. Otoliths were aged by the same reader through 2010. In 2011, a new reader completed the task after finding 100% between-reader agreement on ages estimated by the former reader on otoliths from 2010.

Estimates of Fish Abundance
Transect data were subdivided into elementary distance sampling units (EDSU) consisting either of horizontal intervals between adjacent 10 m bottom contours that were 5 or 10 m deep (1990s) or of 1,000 m intervals that consisted of 10 m layers (2000s). Data collected at bottom depths > 100 m were defined as offshore strata. Data from the 1990s were analyzed using custom software (Argyle et al. 1998). Data collected from 2001-2011 were analyzed with Echoview 4.8 and 5.0 software.

An estimate of total fish density for data from 2001-2011 was made using the formula

$$(1)\ Total\ density\ (fish\,/\,ha) = 10^4 \times \frac{ABC}{\sigma}$$

where 10^4 = conversion factor (m^2·ha^{-1}), ABC = area backscattering coefficient (m^2·m^2) and σ = the mean backscattering cross section (m^2) of all targets between -60 and -30 dB. An echo integration threshold equivalent to a target strength of -70 dB was applied to ABC data. Based on a target strength (TS) – length relationship for alewives (Warner et al. 2002), the applied lower threshold should have allowed detection of our smallest targets of interest (≈20 – 30 mm age-0 alewife). This threshold may have

resulted in underestimation of rainbow smelt density given expected target strengths (Rudstam et al. 2003).

In order to assign species and size composition to acoustic data, we used a technique described by Warner et al. (2009), with different approaches depending on the vertical position in the water column. For cells with depth < 40 m, midwater trawl and acoustic data were matched according to transect, depth layer (0-10, 10-20 m, etc., depending on headrope depth or upper depth of the acoustic cell), and by bottom depth. For acoustic cells without matching trawl data, we assigned the mean of each depth layer and bottom depth combination from the same geographic stratum. If acoustic data still had no matching trawl data, we used a lakewide mean for each depth layer-bottom depth combination. For any cells still lacking trawl composition data, we assigned them lakewide means for each depth layer. Mean mass of species/size groups at depths < 40 m were estimated using weight-length equations from midwater trawl data. In 2001, trawl data were only available for the north nearshore and north offshore strata. To provide an estimate of species composition and size for other strata, the mean of catch proportions and sizes from 2002-2003 were used. For depths ≥ 40 m, we assumed that acoustic targets were large bloater if mean TS was > -45 dB (TeWinkel and Fleischer 1999). Mean mass of bloater in these cells was estimated using the mass-TS equation of Fleischer et al. (1997). If mean TS was ≤ -45 dB, we assumed the fish were large rainbow smelt and estimated mean mass from mean length, which was predicted using the TS-length equation of Rudstam et al. (2003).

As recommended by the Great Lakes Acoustic SOP (Parker-Stetter et al. 2009; Rudstam et al. 2009), we used a number of techniques to assess or improve acoustic data quality. We used the N_v index of Sawada et al. (1993) to determine if conditions in each acoustic analysis cell were suitable for estimation of *in situ* TS. We defined suitability as an N_v value < 0.1 and assumed that mean TS in cells at or above 0.1 was biased. We replaced mean TS in these cells with mean TS from cells that were in the same depth layer and transect with N_v < 0.1. We also estimated noise at 1 m in the 20 log range domain using ambient noise from each transect using either passive data collection or echo integration of data below the bottom echo. To help reduce the influence of noise, we subtracted an estimate of noise which was estimated from ambient noise measurements for each transect. Additionally, we estimated the detection limit (depth) for the smallest targets we include in our analyses. Acoustic equipment specifications, software versions, single target detection parameters, noise levels, and detection limits can be found in Appendices 1 and 2.

Densities (fish/ha) of the different species were estimated as the product of total fish density and the proportion by number in the catch at that location. Total alewife, smelt, and bloater density was subdivided into size- or age class-specific density by multiplying total density for these species by the numeric proportions in each age or size group. Biomass (kg/ha) for the different groups was then estimated as the product of density in each size or group and size or age-specific mean mass as determined from fish lengths in trawls (except as described for depths ≥ 40 m).

Mean and relative standard error (RSE = (SE/mean) x 100) for density and biomass in the survey area were estimated using stratified cluster analysis methods featured in the statistical routine SAS PROC SURVEYMEANS (SAS Institute Inc. 2004). Cluster sampling techniques are appropriate for acoustic data, which represent a continuous stream of autocorrelated data (Williamson 1982; Connors and Schwager 2002). Density and biomass values for each ESU in each stratum were weighted by dividing the stratum area (measured using GIS) by the number of ESUs in the stratum.

RESULTS
Alewife − Alewife density in 2011 (280 fish/ha, RSE = 22%) was the second lowest ever observed and was 15% of the long-term (1992-2010) mean of 1,859 fish/ha. Alewife biomass (3.5 kg/ha, RSE = 25%) in 2011 was 24% of the long-term mean of 14.6 kg/ha but was the second lowest in the time series. Age-

0 alewife density (20 fish/ha, RSE = 21%, Figure 2), was 1.5 % of long-term mean of 1,367 fish/ha and was the lowest of any acoustic survey. Age-1 and older (YAO) alewife biomass was highly variable in the 1990s but the highest values of the time series were in 1995 and 1996. The high biomass in 1996 was in large part the result of a very strong year class in 1995. Biomass of this age group was relatively constant from 2001-2007 (Figure 3), increased in 2008-2010, and then declined by 69% from 2010 to 2011. The decline from 2010 to 2011 indicated that unlike the 1995 year class, the strong 2010 year class did not survive to contribute to higher biomass. The biomass decrease from 2010 to 2011 was the largest one-year decline on record. Approximately half of the decrease between 2010 and 2011 was the result of decreased YAO biomass. In 2011 the YAO group consisted of fish from the 2006-2010 year-classes (Figure 4). Mean age of YAO decreased from 2.1 years in 2010 to 1.3 years (the lowest in the time series) in 2011, and there was a significant decreasing trend in mean age from 2003 to 2011 ($r^2 = 0.60$, $P = 0.015$, Figure 5). The 2010 alewife year-class was the second largest in the time series but high mortality [$-(\log_e N_{t+1} - \log_e N_t) = Z = 2.87$], likely from a combination of predation and an early summer 2011 mortality event of those fish resulted in density at age-1 (208 fish/ha) being similar to the long-term average age-1 density (211 fish/ha). Estimated density of spawners (age-3 and older surveyed in 2011) was the second lowest in the time series. Acoustic results were not consistent with bottom trawl results in terms of abundance; the 2011 alewife estimate from the bottom trawl was similar to the 2010 value, while the acoustic estimate showed a large decrease. However, both surveys indicated that the age-1 alewife (2010 year class) made up most of the population in both numbers and biomass. This resulted in very low numbers of mature individuals and much of the population will remain sexually immature in 2012, which will reduce the probability of a large year class in 2012.
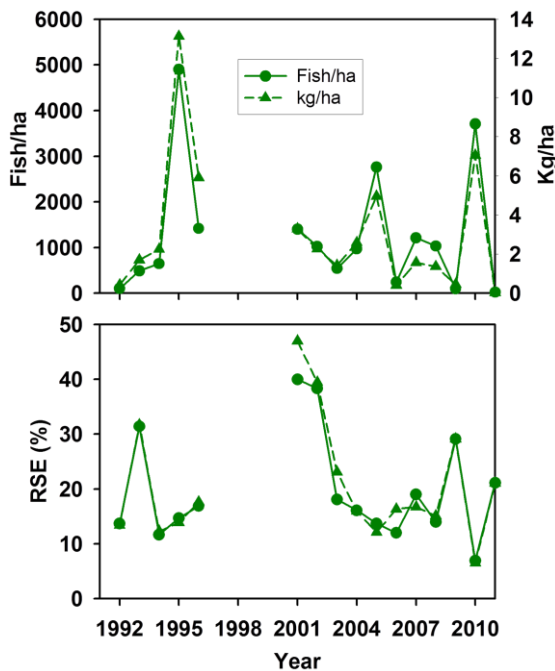

Figure 2. Acoustic estimates of age-0 alewife density and biomass in Lake Michigan, 1992-2011 (upper panel) shown with relative standard error of the estimates (RSE, lower panel).
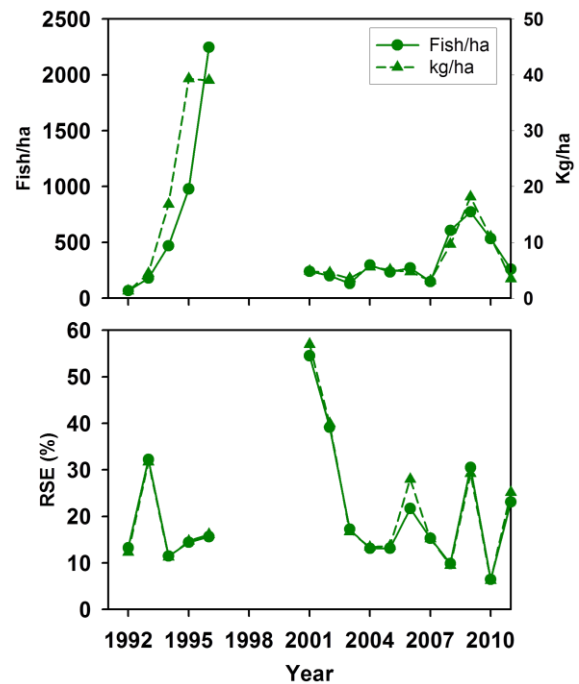

Figure 3. Acoustic estimates of yearling-and-older alewife density in Lake Michigan, 1992-2011 (upper panel) shown with relative standard error of the estimates (RSE, lower panel).
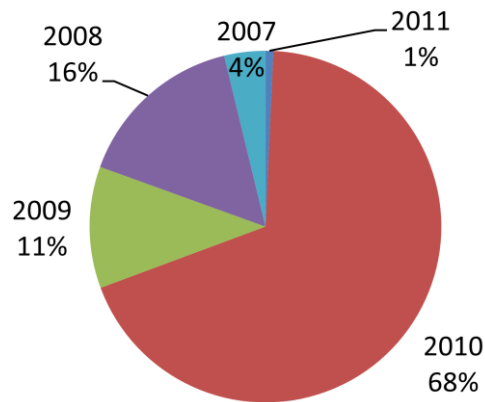
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Figure 4. Percent contribution of alewife year-classes to alewife biomass during 2011. Labels show year class and percent of alewife biomass.
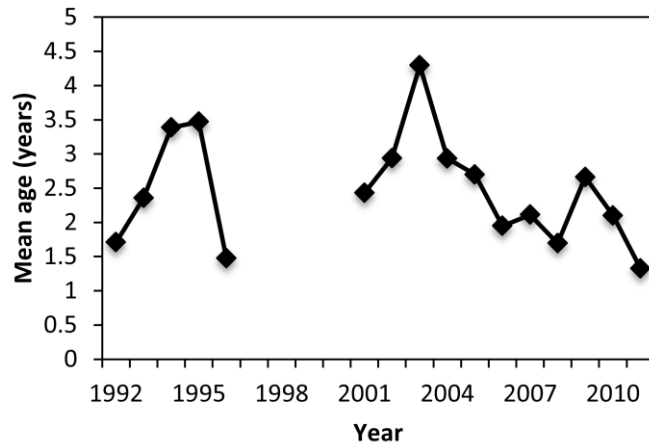

Figure 5. Mean age of YAO alewife in Lake Michigan in 2001-2011.

Rainbow smelt –Density of rainbow smelt generally increased from 2002-2008 (Figure 6), before declining to much lower levels in 2009-2010. However, biomass has been consistently low since 2007. Rainbow smelt density in 2011 (307 fish/ha, RSE = 37%) was similar to the 2010 density. Biomass of rainbow smelt (0.75 kg/ha, RSE = 38%) was similar to 2010 biomass but was only 15 % of the long term mean. Rainbow smelt > 90 mm in length constituted roughly 79% of the population and 88% of biomass. Acoustic survey results were not consistent with bottom trawl results for 2011, as the bottom trawl results indicated that rainbow smelt biomass decreased in 2011 from 2010 (Madenjian et al. 2012).
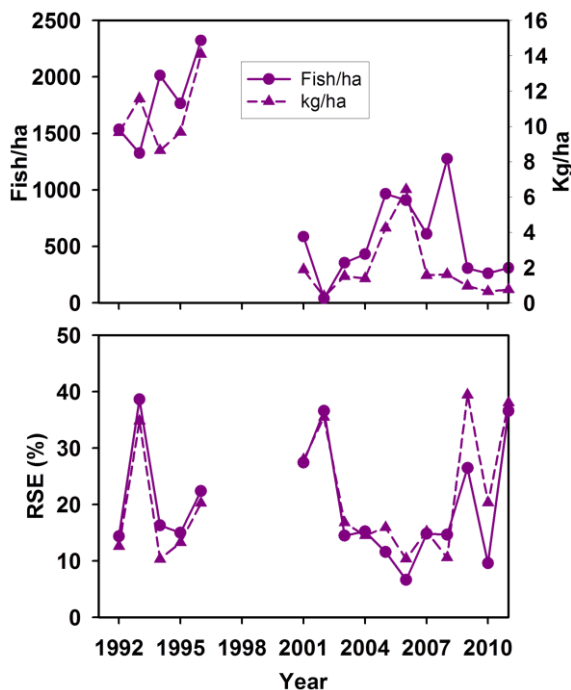

Figure 6. Acoustic estimates of rainbow smelt density and biomass in Lake Michigan in fall 1992-2011 (upper panel) shown with relative standard error of the estimates (RSE, lower panel).

Bloater – Bloater continue to be present at low densities relative to the 1990s. Mean density in 2011 (16 fish/ha, RSE = 25%) was the lowest in the time series, as was bloater biomass (0.6 kg/ha, RSE = 31%). Small bloater showed an increasing trend from 2001-2009 (Figure 7), while large bloater showed no trend during this period (Figure 8). It is not clear what led to the drastic decline in bloater abundance from the 1980s to present. Madenjian et al. (2002) proposed that bloater recruitment and abundance are regulated by internal cycling, and Bunnell et al. (2006) found that during periods of low abundance and recruitment, the sex ratio of bloater is predominantly female, while during periods of high abundance and recruitment sex ratio is more balanced. Given that relatively high levels of age-0 bloater in 2007-2009 (Figure 7) did not recruit to YAO bloaters (Figure 8), we hypothesize

that predation on small bloater by salmonines could be the underlying mechanism (see Warner et al. 2008) as these small fish are found in the same location as alewife and at times can be important to some predators (Elliott 1993; Rybicki and Clapp 1996; Warner et al. 2008). Because bloater become fully recruited to the bottom trawl by age-3 (Bunnell et al. 2006), it seems likely that fish hatched in 2007-2008 would be recruited to the bottom trawl in 2011. Wells and Beeton (1963) suggested that the switch from pelagic to demersal occurred at age-3, while Crowder and Crawford (1984) suggested the switch occurred by age-1 in 1979-1980. However, bottom trawl data from Lake Michigan indicate minimal recruitment of age-3 and older bloater to the bottom trawl from the 2007-2009 year-classes (Madenjian et al. 2012). Both Lake Michigan surveys suggest that recruitment in Lake Michigan is much more limited than in Lake Huron, where high densities of small bloater in 2007-2008 preceded increases in the abundance of larger bloater (Schaeffer et al. 2012; Riley et al. 2012).

DISCUSSION

The results of the 2011 Lake Michigan acoustic survey indicate continued variability in alewife biomass as well as persistently low biomass of rainbow smelt and bloater. Peak alewife biomass was in 1995 and 1996 (≈40 kg/ha), and the two highest values during 2001-2011 (2009-2010) were only half as high as in 1995-1996. In addition to the high degree of variation in alewife biomass, we observed a recent shift to a population that is composed almost entirely of immature fish. This is likely to result in limited egg production in 2012. Total prey fish biomass in 2011 was the lowest ever observed (Figure 9).

As with any survey, it is important to note that trawl or acoustic estimates of fish density are potentially biased and, when possible, we should describe the effects of any bias when interpreting results. With acoustic sampling, areas near the bottom (bottom 0.3-1 m) and the surface (0-3 m) are not sampled well or at all. The density of fish in these areas is unknown. Air-water
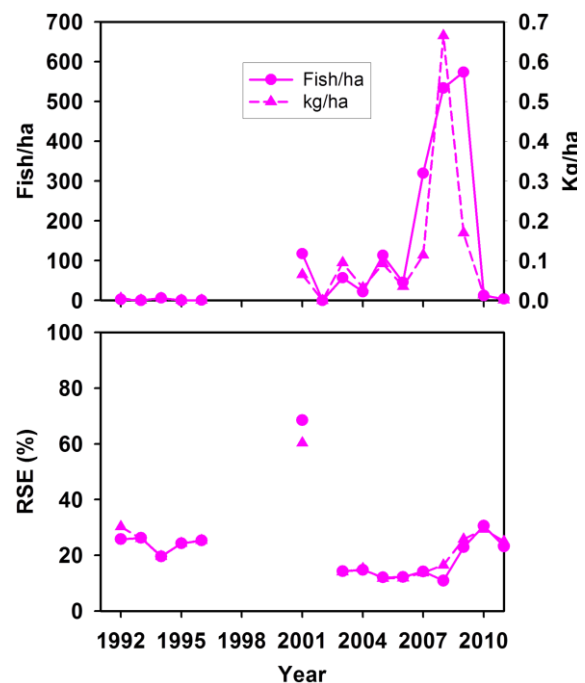

Figure 7. Acoustic estimates of small bloater density and biomass in Lake Michigan in fall 1992-2011 (upper panel) shown with relative standard error of the estimates (RSE, lower panel).
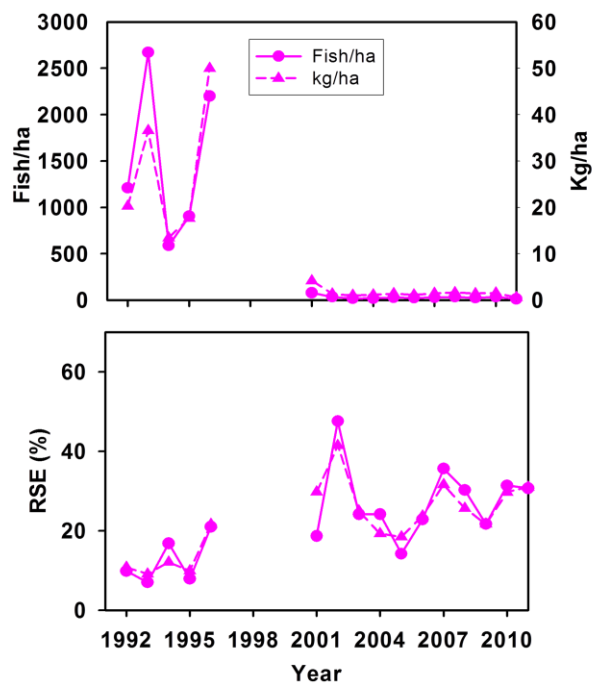

Figure 8. Acoustic estimates of large bloater density and biomass in Lake Michigan in fall 1992-2011 (upper panel) shown with relative standard error of the estimates (RSE, lower panel).
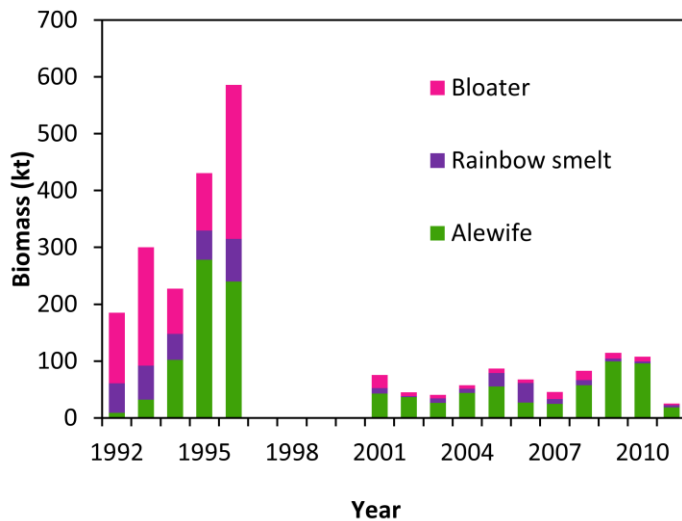
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Figure 9. Acoustic estimates of total prey fish biomass in Lake Michigan, 1992-2011.

interface problems as well as time limitations preclude the use of upward or side-looking transducers. If one assumes that fish available to a bottom trawl with ≈ 1 m fishing height at night are not available to acoustic sampling, it is doubtful that the bottom deadzone contributes much bias for alewife and rainbow smelt because of their pelagic distribution at night. In Lake Michigan, day-night bottom trawling was conducted at numerous locations and depths in 1987 (Argyle 1992), with day and night tows occurring on the same day. After examining these data we found that night bottom trawl estimates of alewife density in August/September 1987 were only 4% of day estimates (D.M. Warner, unpublished data). Similarly, night bottom trawl estimates of rainbow smelt density were ≈ 3% of day estimates. Evidence suggests bloater tend to be more demersal; in Lake Superior, night acoustic/midwater trawl sampling may detect only 60% of bloater present (Yule et al. 2007). Day-night bottom trawl data from Lake Michigan in 1987 suggested that the availability of bloater to acoustic sampling ranged from 7-76%. Slimy sculpins (*Cottus cognatus*) and deepwater sculpins (*Myoxocephalus thompsonii*) are poorly sampled acoustically and we must rely on bottom trawl estimates for these species. Alewife and rainbow smelt (primarily age-0) may occupy the upper 3 m of the water column and any density in this area results in underestimation of water column and mean lakewide density. Depending on season, in inland New York lakes and Lake Ontario, 37-64% of total alewife catch in gill nets can occur in the upper-most 3 m (D.M. Warner, unpublished data). However, highest alewife and rainbow smelt catches and catch-per-unit-effort with midwater tows generally occur near the thermocline in Lake Michigan (Warner et al. 2008; Warner et al. 2012).

We made additional assumptions about acoustic data not described above. For example, we assumed that all targets below 40 m with mean TS > -45 dB were bloater. It is possible that this resulted in a slight underestimation of rainbow smelt density. We also assumed that conditions were suitable for use of *in situ* TS to estimate fish density, which could also lead to biased results if conditions are not suitable for measuring TS (Rudstam et al. 2009) and biased TS estimates are used. However, we identified areas where TS was biased and replaced these biased values with unbiased values from nearby areas in the same depth area. Of 4,424 acoustic analysis cells in 2011, only 85 (2 %) were identified as being unsuitable for estimation of in situ TS. Finally, we assumed that noise levels did not contribute significantly to echo integration data and did not preclude detection of key organisms. This assumption was supported by our estimates of noise and detection limits for targets of interest (Appendix 2).

Prey fish biomass in Lake Michigan remains at levels much lower than in the 1990s, and the estimate of total lakewide biomass (26 kt) from acoustic sampling was the lowest in the time series. This is in contrast to 2008-2010, when biomass was relatively high (but still lower than in the 1990s). This recent variation, resulting primarily from decreased alewife biomass, highlights the dynamic nature of the pelagic fish community in Lake Michigan. The large difference in prey fish biomass in the 1990s and 2000s resulted primarily from the decrease in large bloater abundance, but alewife and rainbow smelt declined as well. Bloater densities showed an increasing trend 2001-2009, with most of the increase driven by increases in small bloater. A similar pattern has been observed in Lake Huron (Schaeffer et al.

2012), but only in Lake Huron has there been any evidence of recruitment to larger sizes, as bottom trawl estimates of large bloater density have increased in recent years in Lake Huron but not in Lake Michigan (Madenjian et al. 2012; Riley et al. 2012; Schaeffer et al. 2012). Pelagic fish biomass was not evenly split among the species present in 2011 (Table 1), and limited recruitment of high densities of small bloater suggests that little progress is being made toward meeting the Fish Community Objectives (FCO, Eshenroder et al. 1995) of maintaining a diverse planktivore community, particularly relative to historical diversity. Bloater and emerald shiner (*Notropis atherinoides*) were historically important species, but bloater currently exist at low biomass levels and emerald shiner have never been detected in this survey. In Lake Huron, collapse of the alewife population in 2003-2004 was followed by resurgence in emerald shiner abundance in 2005-2006 (Schaeffer et al. 2008) and by increased abundance of cisco [*Coregonus artedi*, (Warner et al. 2009)]. Of note in the 2011 Lake Michigan acoustic survey was the capture of one cisco in the northern part of the lake. This one cisco notwithstanding, the between-lake differences in the prevalence of native species persisted in 2011. Given evidence from acoustic surveys from lakes Michigan and Huron as well as the evidence provided by Madenjian et al. (2008), it appears that emerald shiners are suppressed by all but the lowest levels of alewife abundance. Unlike in previous years, in 2011 pelagic fish biomass in Lake Huron was nearly 1.8 times higher than in Lake Michigan (Schaeffer et al. 2012).

While it is not possible to definitively explain the differences in pelagic biomass and fish community composition observed between lakes Michigan and Huron, one potentially important factor is predation by Chinook salmon. Chinook salmon consumption has a strong influence on recruitment success of alewife in Lake Michigan (Madenjian et al. 2005), and statistical catch at age models indicate that abundance of age-1 and older Chinook salmon were on average 42 times more abundant in Lake Michigan than in Lake Huron between 2001-2008 (Iyob Tsehaye, Michigan State University Quantitative Fisheries Center, personal communication; Travis Brenden, Michigan State University Quantitative Fisheries Center, personal communication). Regardless of the reason for the biomass differences in the lakes or the cause(s) for low biomass in Lake Michigan (relative to previous years), prey fish biomass is such that prey availability for predators is likely to be low in 2012. Prey biomass based on the acoustic survey data collected in 2011 (95% CI = 15 – 36 kt) was low relative to the FCO, which calls for biomass levels matched to primary production and predator demand (500-800 kt) and maintenance of a diverse planktivore community. With sculpin biomass from the bottom trawl survey (Madenjian et al. 2012) added to the acoustic biomass of other species, estimated lakewide biomass (31 kt) is still less than the FCO range. It is unclear if the prey biomass levels are matched to primary production (e.g. the maximum that can be supported for the observed primary production levels), and the relationship(s) between primary production and prey fish biomass (if any) are not known.

Table 1. Biomass, RSE, and 95% CI for age-0, YAO, total alewife, rainbow smelt, and bloater estimated from acoustic and midwater trawl data collected in Lake Michigan in 2011.

Species	Biomass (kg/ha)	RSE (%)	95% CI
Age-0 alewife	0.025	21	(0.015,0.034)
YAO alewife	3.4	25	(1.9, 4.9)
Total alewife	3.5	25	(1.9, 4.9)
Rainbow smelt	0.8	38	(0.3, 1.2)
Bloater	0.6	31	(0.3, 0.9)
Total	4.8	23	(2.9, 6.7)

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Appendix 1. Single target detection parameters used in acoustic data analyses in 1992-1996 and 2011.

Parameter	Split[1]	Dual beam 1992-1996	Dual beam 2001-2005
TS threshold (dB)	-77	-60	-77
Pulse length determination level (dB)	6	6	6
Minimum normalized pulse length	0.8	0.32	0.8
Maximum normalized pulse length	1.5	0.72	1.8
Maximum beam compensation (dB)	6	6	6
Maximum standard deviation of minor-axis angles	0.6	NA	NA
Maximum standard deviation of major-axis angles	0.6	NA	NA
Over-axis angle threshold (dB)	NA	NA	-1.0

[1]Although a lower threshold was used in 2001-2011, only targets ≥-60 dB were included as in analyses of the 1990s data.

Appendix 2. Noise levels (mean and range of Sv and TS at 1 m), detection limits, and acoustic equipment specifications in 2011 for the R/V Sturgeon, S/V Steelhead, and M/V Spencer F. Baird.

Vessel	R/V Sturgeon	S/V Steelhead	M/V Spencer F. Baird
Collection software	Visual Acquisition 5.1	Visual Acquisition 5.1	ER60 2.2
Transducer beam angle (3dB)	7.8º split beam	6.9º split beam	6.49 º x 6.53 º split beam
Frequency (kHz)	120	129	120
Pulse length (ms)	0.4	0.4	0.256
Mean of Sv noise at 1 m (dB)	-126[1]	-109[2]	-125[1]
Mean of TS noise at 1 m (dB)	-153	-145	-152
Two-way equivalent beam angle (dB)	-19.34	-20	-20.1
Detection limit (m) for -60 dB target[3]	93	57	87

[1] Mean of values estimated by integrating passive data collected during survey.

[2] Mean of values estimated by integrating areas under the bottom echo for each transect.

[3] Assuming 3 dB singal-to-noise ratio, 6 dB maximum beam compensation, and 6 dB pulse length determination level.